

Cryogenic Insulation Standard Data and Methodologies Project

Center Independent Research & Developments: KSC IRAD Program | Mission Support Directorate (MSD)



ABSTRACT

Extending some recent developments in the area of technical consensus standards for cryogenic thermal insulation systems, a preliminary Inter-Laboratory Study of foam insulation materials was performed by NASA Kennedy Space Center and LeTourneau University. The initial focus was ambient pressure cryogenic boil off testing using the Cryostat-400 flat-plate instrument. Completion of a test facility at LETU has enabled direct, comparative testing, using identical cryostat instruments and methods, and the production of standard thermal data sets for a number of materials under sub-ambient conditions. The two sets of measurements were analyzed and indicate there is reasonable agreement between the two laboratories. Based on cryogenic boiloff calorimetry, new equipment and methods for testing thermal insulation systems have been successfully developed. These boiloff instruments (or cryostats) include both flat plate and cylindrical models and are applicable to a wide range of different materials under a wide range of test conditions. Test measurements are generally made at large temperature difference (boundary temperatures of 293 K and 78 K are typical) and include the full vacuum pressure range. Results are generally reported in effective thermal conductivity (k_e) and mean heat flux (q) through the insulation system. The new cryostat instruments provide an effective and reliable way to characterize the thermal performance of materials under sub-ambient conditions. Proven in through thousands of tests of hundreds of material systems, they have supported a wide range of aerospace, industry, and research projects. Boiloff testing technology is not just for cryogenic testing but is a cost-effective, field-representative methodology to test any material or system for applications at sub-ambient temperatures. This technology, when adequately coupled with a technical standards basis, can provide a cost-effective, field-representative

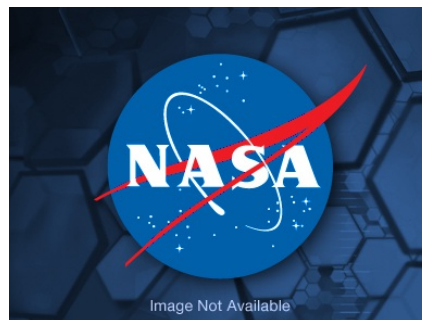
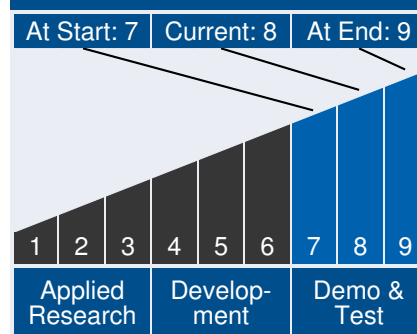


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Technology Maturity



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methodology to test any material or system for applications at sub-ambient to cryogenic temperatures. A growing need for energy efficiency and cryogenic applications is creating a worldwide demand for improved thermal insulation systems for low temperatures. The need for thermal characterization of these systems and materials raises a corresponding need for insulation test standards and thermal data targeted for cryogenic-vacuum applications. Such standards have a strong correlation to energy, transportation, and environment and the advancement of new materials technologies in these areas. In conjunction with this project, two new standards on cryogenic insulation were recently published by ASTM International: C1774 and C740. Following the requirements of NPR 7120.10, Technical Standards for NASA Programs and Projects, the appropriate information in this report can be provided to the NASA Chief Engineer as input for NASA's annual report to NIST, as required by OMB Circular No. A-119, describing NASA's use of voluntary consensus standards and participation in the development of voluntary consensus standards and bodies.

ANTICIPATED BENEFITS

To NASA funded missions:

To make cryogenics more practical to store and transfer, whether on Earth or in space or other destinations, benchmark thermal performance data are needed. To obtain such data, standard approaches, methodologies, and apparatuses are also needed. This project addresses the problem in a three pronged approach: materials science and development; testing methodologies and equipment. Programs and projects supported include, for example: SLS vehicle, Game Changing Technology - Cryogenic Composite Tanks, Advanced Exploration Systems - Liquid Hydrogen and Liquid Oxygen Ground Operations Demonstrations, SBIR - materials research projects



2 Conference Papers
2 Peer Reviewed Papers
2 Publications

Management Team

Program Director:

- Burton Summerfield

Program Executive:

- Karen Thompson

Program Manager:

- Nancy Zeitlin

Project Manager:

- Pamela Mullenix

Principal Investigator:

- James Fesmire

Co-Investigator:

- Adam Swanger

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(collaboration with companies), Cryogenic Spill Protection for LNG Cryofuel Systems, CIF - Multifunctional Structural Thermal Composites, NIAC - Lunar Regolith Regolith-Derived Heat Shield, etc.

This project is one part of a larger effort that has ensued since the completion of the NASA Internal Research and Development (IR&D) project *Technologies to Increase Reliability of Thermal Insulation Systems* funded by the Space Operations Mission Directorate (SOMD) in 2004.

The standard reference data sets produced are available for cryogenic systems design, analysis, and development. Future technical consensus standards are envisioned for both test methods and materials practices. Specific test methods would be formulated for cylindrical and flat plate geometries covering absolute and comparative approaches, as required by mutual industry needs. Standard data sets for specific materials would then be produced through a round robin of cryogenic testing among laboratories, thus enabling new standard material practices.

To NASA unfunded & planned missions:

Existing information combined with the latest research test data has been organized to help solve the problems presented by the thermal environments of the Earth, launch ascent, Moon, and Mars. The Cryogenics Test Laboratory at NASA Kennedy Space Center has produced much new information on cryogenic and vacuum environments including high vacuum (Moon or Earth orbit), soft vacuum (Mars or launch ascent), and no vacuum (Earth atmosphere with or without humidity). The materials include multilayer insulation, aerogel blankets, aerogel bulk-fill, foams, composites, and many other constructions.

Technology Areas

Ground & Launch Systems Processing (TA 13)

- Launch Propulsion Systems (TA 1)
- In-Space Propulsion Technologies (TA 2)
- Space Power & Energy Storage (TA 3)
- Human Health, Life Support & Habitation Systems (TA 6)
- Human Exploration Destination Systems (TA 7)
- Nanotechnology (TA 10)
- Materials, Structures, Mechanical Systems & Manufacturing (TA 12)
- Thermal Management Systems (TA 14)

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To other government agencies:

Energy use, efficiency, conservation, and alternatives are critical to the future on Earth and in space, only 10% of total usage has to do with electrical energy while 90% is thermal energy! To have basic information on low-temperature thermal insulation is an enabling and cross-cutting benefit for NASA and industrial needs nationwide and on a global scale. Cryogenic insulation requirements are spread throughout propulsion, airframe, architecture, and launch systems. Historically, programs have assumed others would cover this work or that the work would be covered by another related system area. The work is discipline advancing and the development of standards has the potential to benefit many programs and projects. The work addresses issues common to propulsion, life support, power, and science (refrigeration) systems, including flight, in-space, and surface systems. Project advances both NASA-wide requirements and National directives by developing standard data and testing for cryogenic insulation materials. Strategic partnerships ensure maximum benefit to NASA objectives for technology advancement, engineering information, and technical capabilities.

To the commercial space industry:

What is the point? New thermal materials and thermal management systems are needed for future space launch vehicles and the space exploration enterprise. This critical area of new technology is now in a competitive global launch market. Thermal insulation must be considered as an integrated system, not merely an add-on element. The end of insulation as a bolt-on element is the underlying theme of this R&D project. Development of thermal insulation systems technology should proceed from basic understanding of both high temperature and low temperature requirements (hot side + cold side) as well as structural and thermal requirements. To address the total energy efficiency picture of any complex space hardware system the development must also consider both active systems such as cryocoolers and passive systems such as foam materials. Multifunctional thermal insulation systems are a key to technological advancements that can be achieved by considering materials, testing, and engineered applications.

To the nation:

The need for practical thermal conductivity data for cryogenic applications continues to grow in areas such as oil & gas, electrical power, refrigerated transport, aerospace, aircraft, ground transportation, industrial processes, semi-conductor manufacturing, and many others. New materials, for example, aerogel blankets, aerogel bulk-fill, glass bubbles, polyimide foams, are now commercially available and are being applied for low-temperature insulation solutions and broad

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industrial application. New multilayer and composite insulation materials have also been developed for high levels of thermal performance to meet the growing demands for energy efficiency and environmental responsibility in today's economy.

Responding to high level objectives in both energy efficiency standards and technical consensus standards, this project advances both NASA-wide requirements and National directives by developing standard data and testing for cryogenic insulation materials. Strategic partnerships ensure maximum benefit to NASA objectives for technology advancement, engineering information, and technical capabilities. The relevant Agency and Federal directives and initiatives are listed as follows:

1. OMB Circular No. A-119, *Federal Participation in Development & Use of Voluntary Consensus Standards & in Conformity Assessment Activities*
2. *Memorandum for the Heads of Executive Departments and Agencies* (2012)
3. *Technical Standards for NASA Programs and Projects*, NPR 7120.10 (2011)
4. *The U.S. Materials Genome Initiative* (2011)

This project has enabled the development and publication of two new international standards on the subject of below-ambient (and cryogenic) thermal insulation systems, materials, and testing.

Thermal insulation plays a significant and sometimes enabling role in cryogenic systems. The emerging cryofuels enterprises including LNG and LH₂ are a particular challenge due to the transient type operational processes to be addresses and the competitive economic targets to be met. The new technical consensus standards are but one step toward providing standard thermal performance data to support the design practices for cryogenic systems. Benchmark thermal performance data provided by the new patented test instruments, including effective thermal conductivity and heat flux, can ultimately be used to calibrate comparative type instruments and support detailed studies of insulation system designs for specific applications. At least 10 future technical consensus standards are planned for both test methods and materials practices to support the cryogenic industry and further the proliferation of new industrial opportunities in the areas of transportation and energy.

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DETAILED DESCRIPTION

Although some standards exist for thermal insulation, few address the sub-ambient temperature range and cold-side temperatures below 100 K. Standards for cryogenic insulation systems require cryostat testing and data analysis that will allow the development of the tools needed by design engineers and thermal analysts for the design of practical cryogenic systems. Thus, this critically important information can provide reliable data and methodologies for industrial efficiency and energy conservation.

The needs for technical standards for thermal insulation systems are growing in the US and worldwide. Energy efficiency and conservation needs -- of which thermal insulation systems are a key part -- are a top priority for economic, national security, and technological concerns. The emphasis on technical consensus standards is a clear directive from both government policy and market economic drivers.

Summarized here are the most recent and relevant government policy directives to encourage technical standards development and energy efficiency technology implementation. The reference federal agency is NASA and the target subject area is thermal insulation systems for low-temperature applications. Here is a list of the relevant documents:

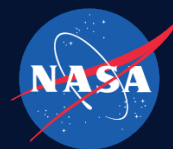
1. OMB Circular No. A-119, *Federal Participation in the Development and Use of Voluntary Consensus Standards and in Conformity Assessment Activities*.
2. *Memorandum for the Heads of Executive Departments and Agencies*, document M-12-08 dated January 17, 2012.
3. NPR 7120.10, *Technical Standards for NASA Programs and Projects*, Effective Date: April 22, 2011.

On February 4, 2011, the President released *A Strategy for American Innovation: Securing Our Economic Growth and Prosperity* and directed Federal agencies to increase their efforts to catalyze technology breakthroughs to advance national priorities. Pursuant to the Strategy for American Innovation, the Office of Science and Technology Policy (OSTP), the Office of Management and Budget (OMB), and the Office of the United States Trade Representative (USTR) are the *Memorandum for the Heads of Executive Departments and Agencies* was issued to clarify principles guiding Federal Government engagement in standards activities that can help address national priorities.

This R&D project was formulated in response to these agency and national objectives for technical

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standards. A preliminary Inter-Laboratory Study of foam insulation materials was conducted by NASA Kennedy Space Center (KSC) and LeTourneau University (LETU). The initial focus was ambient pressure (no vacuum) cryogenic boil off testing using two identical Cryostat-400 flat-plate instruments. Completion of a new test facility at LETU has enabled comparative testing, using similar methods, and the production of standard thermal data sets for cellular glass insulation material under cryogenic conditions. Test measurements were made at both KSC and LETU for comparative analysis. The results show reasonable agreement between the two laboratories. These initial measurements were made at the approximate boundary temperatures of 293 K and 78 K, the results of which are reported in comparative effective thermal conductivity (comparative ke) and mean heat flux (q).

The main challenge is the production of standardized thermal data sets for cryogenic insulation materials and systems. This project took up the challenge and made progress in three ways. The first was to produce a cataloged set of reference test specimens of cellular glass material. Other materials have been identified for future reference test specimens. Second was to conduct a preliminary interlaboratory study of the cellular glass material using the same equipment and methods (Cryostat-400 instrument). The third way was to show the practicality of using boiloff calorimetry to obtain thermal data for stack-ups of different materials (composite panels and insulation materials alike). The boiloff method, being a direct measure of heat energy, provides effective test solutions where other existing commercial methods fall short or are not possible.

In conjunction with this project, two new standards on cryogenic insulation were recently published by ASTM International: C1774 and C740. Following the requirements of NPR 7120.10, *Technical Standards for NASA Programs and Projects*, the appropriate information in this report can be provided to the NASA Chief Engineer as input for NASA's annual report to NIST, as required by OMB Circular No. A-119, describing NASA's use of voluntary consensus standards and participation in the development of voluntary consensus standards and bodies. Further standards in the area of cryogenic insulation systems have been targeted for future development.

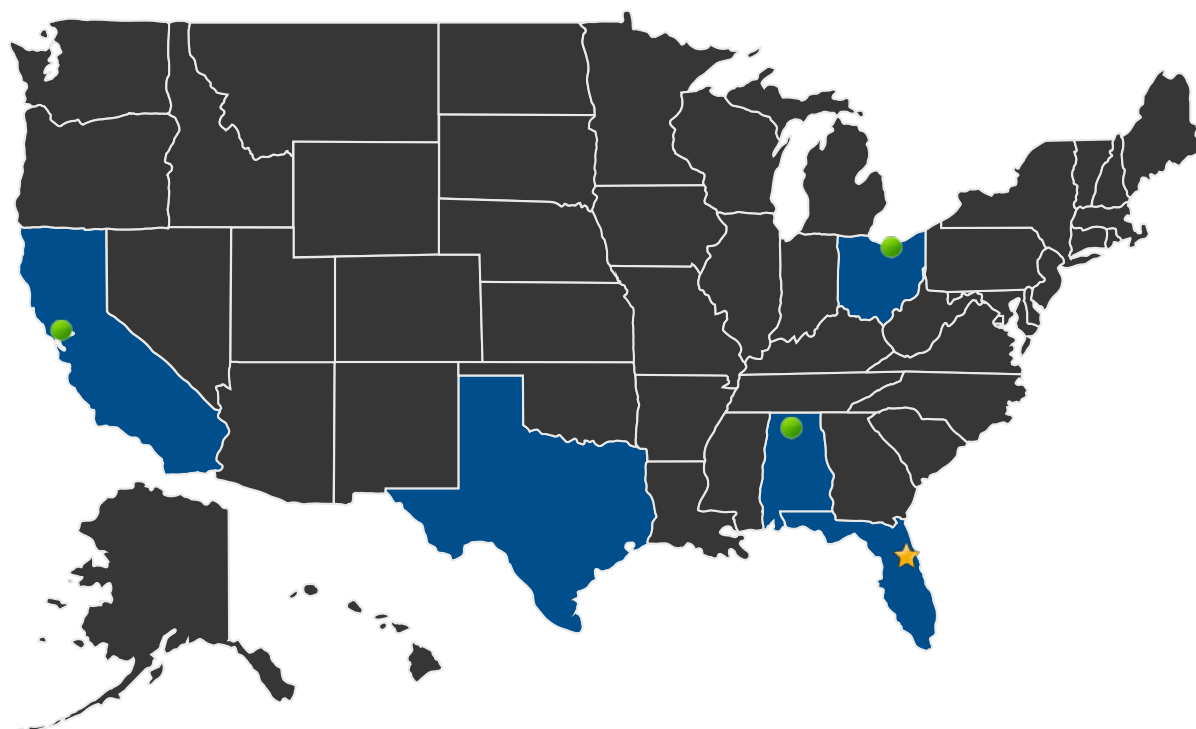
This project involved a number of tasks that were synergetic with other projects under Advanced Exploration Systems, Center Innovation Fund, Game Changing Technology, and others. Compliance issues associated with PVS systems requirements was a major hit on resources in 2013 thus making this leveraging among projects crucial for this work. Three New Technology Reports, three peer-reviewed publications, and one full patent application were also produced in conjunction with this project. Additional publications and patents are pending.

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U.S. LOCATIONS WORKING ON THIS PROJECT



■ U.S. States With Work

★ **Lead Center:**
Kennedy Space Center

● **Supporting Centers:**

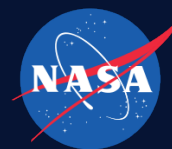
- Ames Research Center
- Glenn Research Center
- Marshall Space Flight Center

Other Organizations Performing Work:

- Letourneau University (Longview, TX)

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Contributing Partners:

- NIST
- Letourneau University
- University of Central Florida (UCF)
- ASTM International

PROJECT LIBRARY

Conference Papers

- Cylindrical boiloff calorimeters for testing of thermal insulations
 - (<https://techport.nasa.gov:443/file/16549>)
- Flat plate boiloff calorimeters for testing of thermal insulation systems
 - (<https://techport.nasa.gov:443/file/16550>)

Peer Reviewed Papers

- Cryogenic insulation standard data and methodologies
 - (<https://techport.nasa.gov:443/file/16551>)
- Standardization in Cryogenic Insulation Systems Testing and Performance Data
 - (<https://techport.nasa.gov:443/file/16552>)

Publications

- ASTM C1774 - Standard Guide for Thermal Performance Testing of Cryogenic Insulation Systems
 - (<http://www.astm.org/Standards/C1774.htm>)
- ASTM C740 - Standard Guide for Evacuated Reflective Insulation In Cryogenic Service
 - (<http://www.astm.org/Standards/C740.htm>)

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DETAILS FOR TECHNOLOGY 1

Technology Title

Cryogenic thermal insulation systems

Technology Description

This technology is categorized as a hardware system for ground scientific research or analysis

The close relationship between industrial energy use and cryogenics drives the need for optimized thermal insulation systems. Emerging cryofuels usage is enabled by adequate isolation of the liquid hydrogen or liquefied natural gas from the ambient environment. Thermal performance data for the total insulation system, as rendered, are essential for both engineering designs and cost-benefit decisions involving comparisons among alternatives. These data are obtained through rigorous testing with suitable apparatus and repeatable methods. Properly defined terminology, analysis, and reporting are also vital. Advances in cryogenic insulation test apparatus and methods have led to the recent addition of two new technical standards of ASTM International: C1774 - *Standard Guide for Thermal Performance Testing of Cryogenic Insulation Systems* and C740 - *Standard Guide for Evacuated Reflective Cryogenic Insulation*. Among the different techniques described in the new standards is the cylindrical boiloff calorimeter for absolute heat measurement over the full range of vacuum pressure conditions. The details of this apparatus, test method, and data analysis are given. Benchmark thermal performance data, including effective thermal conductivity (k_e) and heat flux (q) for the boundary temperatures of 293 K and 77 K, are given for a number of different multilayer insulation (MLI) systems in comparison with data for other commonly-used insulation systems including perlite powder, fiberglass, polyurethane foam, and aerogels.

Capabilities Provided

Through ASTM International, Committee C16 on Thermal Insulation, two new standards were recently published: ASTM C1774 - *Standard Guide for Thermal Performance Testing of Cryogenic Insulation Systems* (2013) and ASTM C740 - *Standard Guide for Evacuated Reflective Cryogenic Insulation* (2014). Both standards are comprehensive guides that provide the necessary terminology, analytical approaches, and reporting requirements for the technology area of cryogenic insulation systems. Advances in test apparatus, methods, and materials have provided a foundation for these new standards.

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The C1774 Guide covers different approaches to both boiloff calorimetry and electrical power methods of for thermal performance measurement in sub-ambient temperature environments. The test apparatuses (apparatus) designed for these purposes are divided into two categories: boiloff calorimetry and electrical power. Both absolute and comparative apparatuses methods are included. These testing approaches methods are applicable to the measurement of a wide variety of specimens, ranging from opaque solids to porous or transparent materials, and a wide range of environmental conditions including measurements conducted at extremes of temperature and with various gases and over a range of pressures. Of particular importance is the ability to test highly anisotropic materials and systems such as multilayer insulation (MLI) systems. The guide provides information for the laboratory measurement of the steady-state thermal transmission properties and heat flux of thermal insulation systems under cryogenic conditions. Thermal insulation systems may be composed of one or more materials that may be homogeneous or non-homogeneous; flat, cylindrical, or spherical; at boundary conditions from 4 to 400 K; and in environments from high vacuum to an ambient pressure of air or residual gas. A key aspect of this guide is the notion of an insulation system, not an insulation material. Under the practical use environment of most cryogenic applications even a single-material system can still be a complex insulation system.

The C740 guide covers the baseline heat flux or thermal conductivity data, performance considerations, typical applications, manufacturing methods, material specification, and safety considerations in the use of MLI systems in cryogenic service. The technology of evacuated reflective insulation, or MLI, first came about in the 1950s and 1960s primarily driven by the need to liquefy, store, and transport large quantities of liquid hydrogen and liquid helium. MLI systems often involve warm boundary temperatures in the range of 300 K or higher and cold boundary temperatures ranging from 4 K to 111 K, but any temperature below ambient is applicable. Insulation systems of this construction are used when heat flux values well below 10 W/m² are needed for an evacuated design. Heat flux values approaching 0.1 W/m² are also achievable. For comparison among different systems, as well as for space and weight considerations, the effective thermal conductivity of the system can be calculated for a specific total thickness. Effective thermal conductivities of less than 1 mW/m-K [R-value 143] are typical and values on the order of 0.01 mW/m-K have been achieved [R-value 14,300]. Thermal performance can also be described in terms of the effective emittance of the system, or E_e. These systems are typically used in a high vacuum environment (evacuated), but soft vacuum or no vacuum environments are also applicable. A welded metal, vacuum-jacketed (VJ) enclosure is often used to provide the vacuum environment. MLI systems are generally used when lower heat leakage rates than those obtained with other evacuated insulations are required. Other evacuated insulations include, for example,

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perlite powder, glass bubbles, or aerogel bulk-fill, which can provide heat flux values in the range of 5 to 20 W/m². The choice for an MLI system may be dictated by the value of the cryogenic fluid being isolated or by weight or thickness limitations imposed by the particular application.

Applications generally fall into the following categories: storage, transfer, thermal protection, and low-temperature processes. Very low temperature (4 K and below) refrigeration for large-scale superconducting magnets, RF cavities, and other devices is a major technical capability for basic physics research world-wide.

Potential Applications

Potential applications include broad usage in the areas of transportation, energy, cold chain shipping of foods and pharmaceuticals, building construction, thermal management systems, and general materials science research. Future technical consensus standards are envisioned for both test methods and materials practices. Specific test methods would be formulated for cylindrical and flat plate geometries covering absolute and comparative approaches, as required by mutual industry needs. Standard data sets for specific materials would then be produced through a round robin of cryogenic testing among laboratories, thus enabling new standard material practices. Energy efficiency, system control, and operational safety are inter-related aspects of deciding the best thermal insulation system for a particular application. The emerging cryofuels enterprises including LNG and LH₂ are a particular challenge due to the transient type operational processes to be addressed and the competitive economic targets to be met.

Performance Metrics

Metric	Unit	Quantity
Heat Flux	W/m ²	1
Thermal Conductivity	mW/m-K	0.1